

THE CHILEAN LEU FUEL FABRICATION PROGRAM. STATUS REPORT

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ABSTRACT

The U_3Si_2 LEU fuel manufacturing program started in 1998 for Chile's RECH-1 reactor, being completed this year with the assembly of four fuel elements (FE) and thus resulting in 48 FE delivered to the reactor. These FE have a density of 3.4 MgU /m³. Four of them, called "leaders", were early introduced into the reactor core for qualification purposes, two in December 1998 and two in July 1999. Up to date, they have achieved a burn-up of 32% and 30 % respectively, and have shown excellent irradiation behavior at inspections scheduled by the RECH-1 irradiation follow-up program. During 2002 a reference nucleus comprising 32 LEU fuel elements was configured at the RECH-1, thus achieving the LEU conversion goal.

In March 2003, Chile's Fuel Fabrication Plant delivered one FE to the Petten-HFR, and its irradiation, which started in May 2003, will end by August 2004 after achieving 55% burn up. This irradiation qualification service will finish in the year 2005 with PIE tests, as established in a contractual agreement between the IAEA, NRG, and CCHEN. These fabrication and irradiation efforts are the final results of an internal R&D program, that nowadays has an U- 7% Mo alloy development in progress. Finally, all these fabrication activities have comprised quality issues that have been addressed via the implementation of a QMS that has resulted in an ISO 9001 Certification obtained in March 2003.

1. Introduction

Chile's RECH-1 reactor, a 5 MW open pool reactor, has been in operation since 1974, and in 1985 was converted from HEU (80% enrichment) to MEU (45% enrichment) fuel. In 1995 a LEU U_3Si_2 -Al fuel fabrication program started with the licensing and implementation stage of the fuel fabrication plant. A qualification stage followed in 1998 that resulted in the fabrication of four fuel elements. They were introduced in the reactor core, two in December 1998 and two in July 1999, as "leader" LEU fuel elements. Since 1999 the standard fuel fabrication has been in progress, resulting in 44 fuel elements delivered to the reactor by December 2002. The program will finish this year with the final delivery of the last 4 fuel elements.

This report presents the main results of this fabrication program and a summary of other activities generated during its development: fabrication and qualification optimization involving the external irradiation of one fuel element at the Petten HFR, the current R&D of U –Mo alloys, and ISO 9001 certification.

2. The RECH-1 fuel element

The LEU U_3Si_2 - Al RECH-1 fuel element has a nominal mass of 214,8 g of U-235, and consists of 16 fuel plates, two side plates, and two end pieces: one filter box, and one nozzle (end

adapter). The fuel plates have different core densities depending on their relative position in the fuel box: the 2 external plates have a nominal core density of 1.7 MgU/m^3 , and the 14 internal fuel plates have a nominal core density of 3.4 MgU/m^3 . These 16 fuel plates are attached to the two side plates by roll swaging and thus producing the fuel box section; the filter box and nozzle are attached to the fuel box section by welding. All the structural components of the fuel element are 6061 Aluminum [1]. A general view of the fuel element is presented in Fig.1.

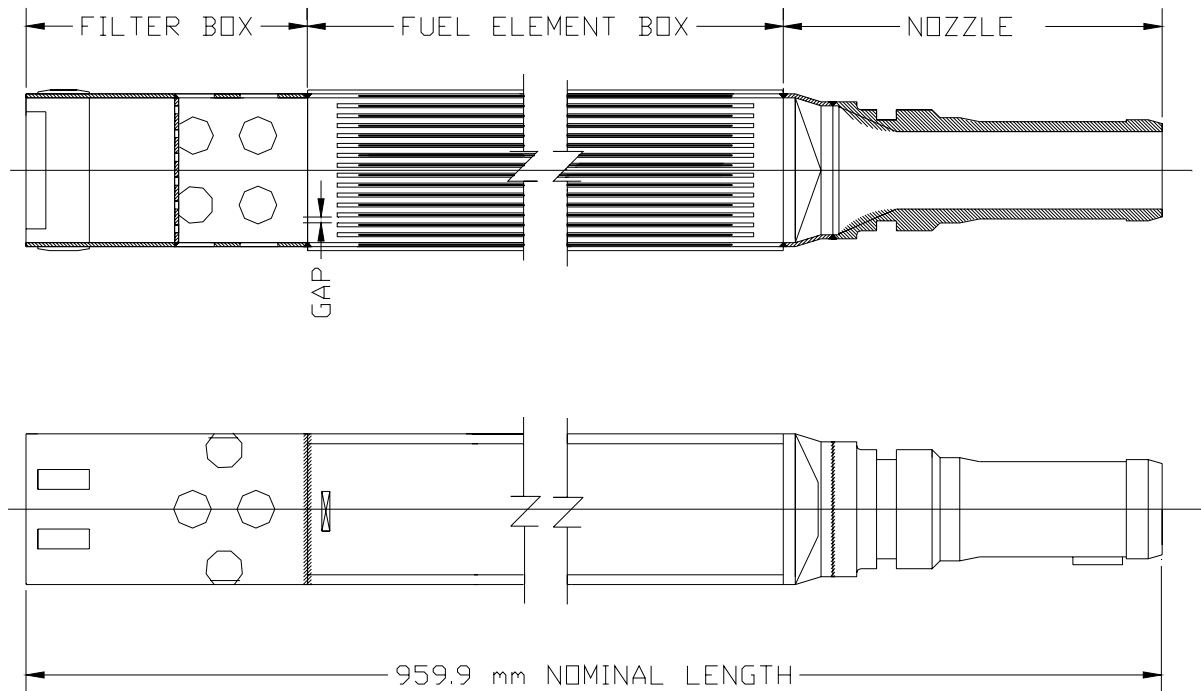


Fig. 1 General view of the standard RECH-1 Fuel Element.

The fuel specification was obtained from the 1998 development and qualification stages [1]. The main specified nominal values are:

- U^{235} content, external plates : 7.16g +/- 2 %
- U^{235} content, internal plates : 14.32g +/- 2 %
- U^{235} content per fuel element : 214.8g +/- 2 %
- U per fuel element, total : 1087.2g +/- 2 %
- U density, core internal plates : 3.4 MgU/m^3
- U homogeneity, external plates : 102.81 mgU/cm^2 +/- 20%
- U homogeneity, internal plates : 205.63 mgU/cm^2 +/- 20%
- Fuel plate core length : 586.0 mm
- Fuel plate core width : 60.15 mm (+0.55/-0.45 mm)
- Fuel plate core thickness : 0.61 +/- 0.02 mm
- Cladding thickness, 6061 Al : 0.46 +/- 0.03 mm
- Hydraulic gap between plates : 3.17 mm (2.92 mm min.)

3. LEU fuel fabrication program

The LEU fuel fabrication program comprised the following stages:

- Development stage, 1995-1997.
In this stage the main results were the fuel specifications, the implementation of the fuel fabrication plant, and the licensing of the fabrication process.
- Fabrication qualification stage, 1998.
In this stage, four fuel elements were fabricated and the fabrication process was submitted to QA inspection by the reactor operator and by the regulatory body. In these four fuel elements, the filter plate was removed from the filter box end piece in order to facilitate the visual inspections during their irradiation.
- Standard fuel fabrication, 1999-2003.
From 1999 and up to December 2002, 44 standard fuel elements were produced and delivered to the RECH-1 reactor. 4 final fuel elements are expected for the end of 2003 and these fuel elements will include some structural changes as shown in figure 2.

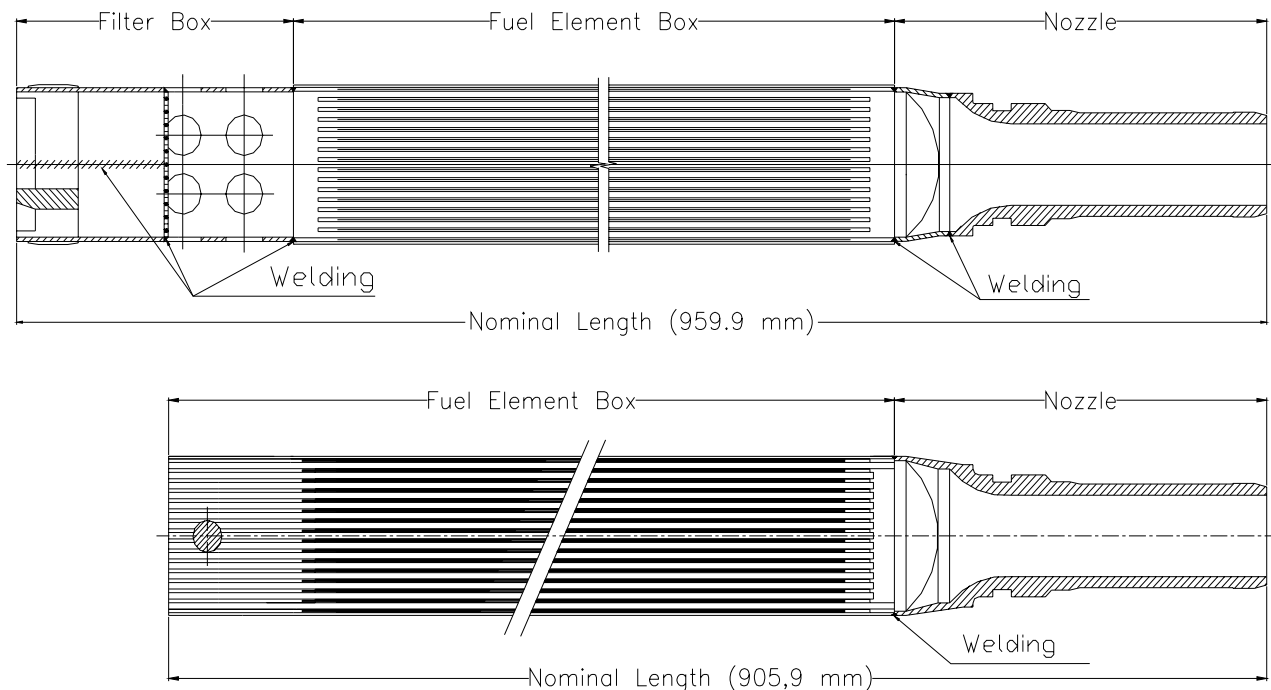


Figure 2. General view of the standard and modified RECH-1 fuel element.

The main results of this fabrication stage are the following:

- In the fuel plates fabrication process, a total of 804 fuel plates were fabricated. Only 31 fuel plates presented non-conformances to specified fabrication requirements. The main initial non-conformances were in the fuel core length, which was corrected

including extra cold rolling passes when needed. Up to date no dog boning has been detected in the fabrication controls and only 11 fuel plates have been rejected being out-of-core fuel particles (remote islands) the main cause for rejection. A graph indicating the type and number of non-conformances is presented in figure 3. A homogeneity measurement technique was developed and homologated due to the lack of gamma scanning equipment.

- In the fuel element assembly process a total of 44 (48 are expected) fuel elements were assembled. Pull test gave an average of 61 N/mm for the roll swaging of the fuel plates. The hydraulic gap average value obtained was 3.17 mm with an assured value > 2.92 mm. For the welding assembly operations involving TIG welding procedures, a welding device that minimizes distortion was implemented, thus delivering fuel elements fully compliant with dimensional specifications.

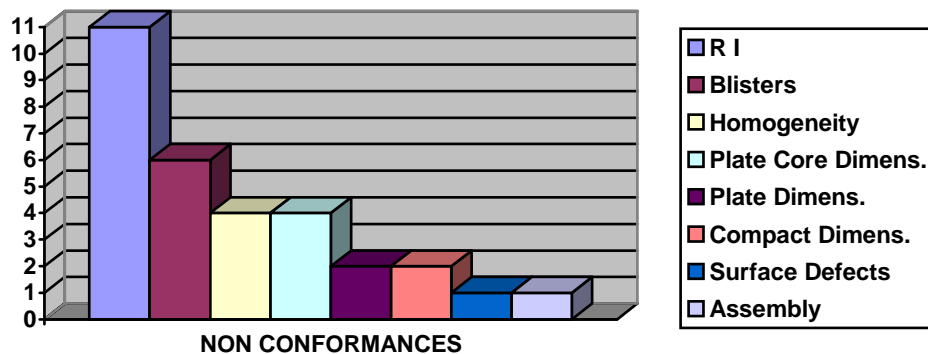


Figure 3. Fuel plate's type of non-conformances

- The main expected goal from this fabrication program, i.e. the RECH-1 conversion to LEU fuel, was achieved on November 2002 when the RECH-1 was submitted to a critical configuration including 20 LEU fuel elements. After this, an experimental configuration with 32 LEU fuel elements was achieved and maintained [2]. It is worth mentioning that this was the first time that a research reactor was operational and fully converted to U_3Si_2 LEU fuel in Latin America. Currently, the RECH-1 reactor operates with a mixed core comprised by 26 HEU (45% U-235) fuel elements and 8 LEU (19,75% U-235) fuel elements. Whenever the discharge burn-up by the HEU fuel elements is achieved, they will be replaced by LEU fuel elements [2]. This procedure will be in effect up to May 2006, as a limit date agreed with the DOE for the transition from HEU to LEU fuel within the framework of the program for the spent fuel return to its country of origin.

4. Fabrication and Qualification Optimization.

By the year 2000, the fabrication program in progress at that time pointed out two main issues in which optimization was possible and needed:

- Fabrication issues: mainly related to QC issues in which implementation and training in ultrasonic and gamma scanning were needed, to improve the controls and measurements for the metallurgical bond and the U^{235} content in the fuel plates, respectively.
- Qualification Issues: the current operation of the RECH-1 reactor indicated that 55% burn up would be achieved by the year 2008 at best.

These issues had been addressed and solved through the implementation of a technical cooperation project supported by IAEA: Project CHI/4/021. This technical cooperation project will soon allow the implementation at the fuel fabrication plant of the ultrasonic and Gamma scanning tests for fuel plate's fabrication.

What's more, it has made possible a contract (2001-937) between IAEA, Nuclear Research and Consultancy Group (NRG), and CCHEN, concerning Irradiation and post-irradiation tests for qualification of a fuel element fabricated in Chile. The contract was signed in November 2001, and the transfer of property of the fuel element fabricated at CCHEN - after the inspections and acceptance by NRG- was made in October 2002. The transport of the fuel element from Chile to Holland was made in March 2003, and the irradiation started in May 16, 2003.

The irradiation (experiment TP 349 CHIP) will proceed for about 15 months, when the expected 55% discharge burn-up will be achieved. PIE tests are also considered in the contract.

5. Development of U-Mo Alloys

Considering the international development of the so-called high density LEU fuels, CCHEN's fuel fabrication plant started these year R&D activities about the U-Mo fuels. The U-Mo composition range of choice was 7 to 10 wt % Mo, considered the most promising composition range for high-density fuels [3,5,6,7]. The U-Mo alloys were produced by induction melting in an argon atmosphere, and homogenized at 980°C for 72 hours [3]. A solid-state phase transformation study of the meta-stable gamma phase in the temperature range of 400 to 610° C was performed and the results obtained using metallography, XRD and micro hardness, are the following:

- It was established that the $\gamma \rightarrow \gamma + \alpha$ continuous precipitation at the grain boundaries, takes place at temperatures $> 500^\circ \text{C}$.
- The $\gamma \rightarrow \alpha + \gamma'$ transformation, inside the grains, takes place at all temperatures below the eutectoid reaction temperature, but requires a very long transformation time [7].
- Finally, 3 stability fields for the TTT diagram are present: γ , $(\gamma + \alpha)$, $(\alpha + \gamma')$. Below 500° C precipitation is the dominant mechanism; above 500° C, both mechanism are competitive and there is a superposition of the transformation fields [4].

In figure 4, only the curves for the start of the transformations are shown due to the long time needed for the finish of the transformations; Mo is a substitutional atom in the U lattice [8].

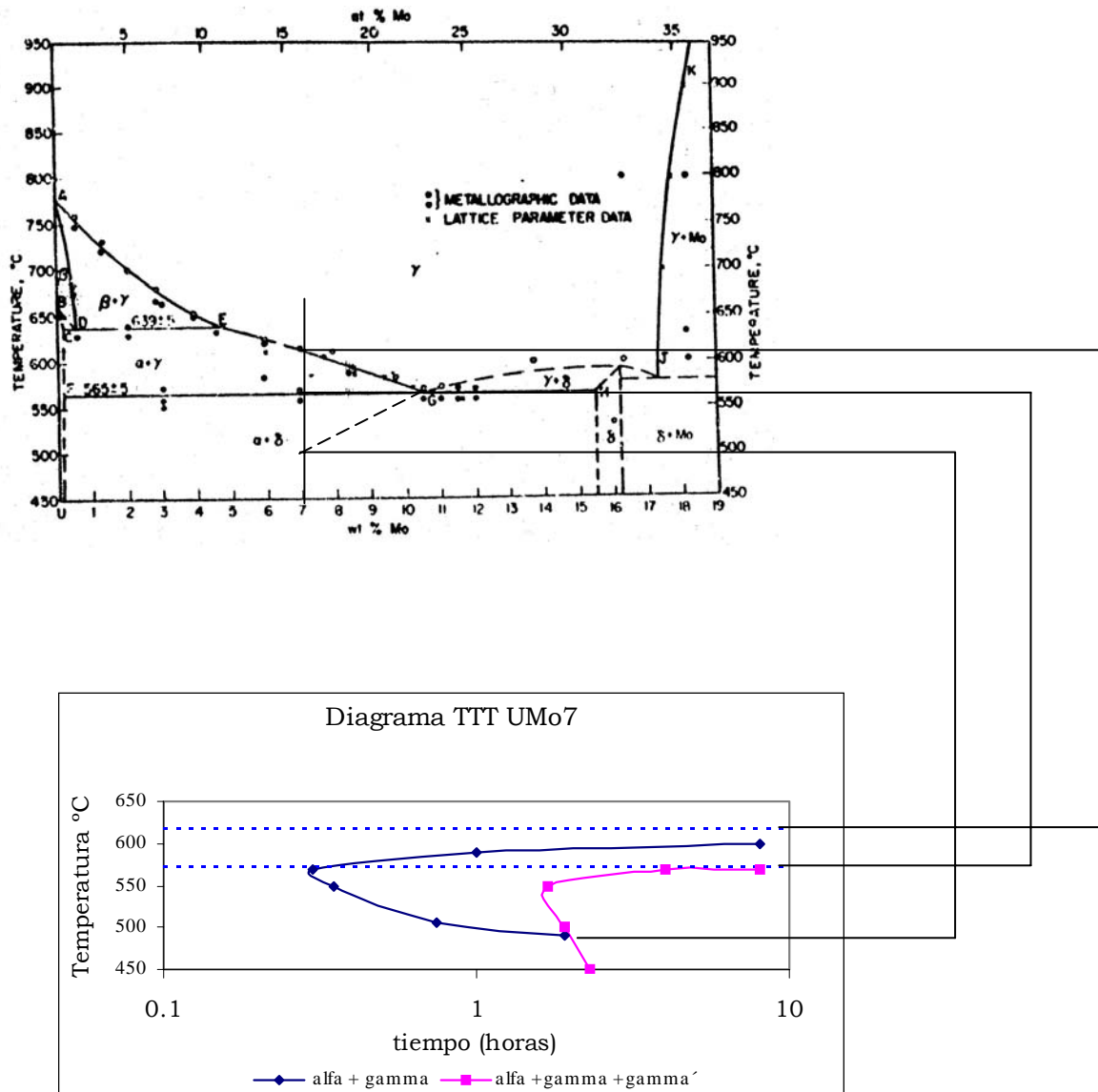


Figure 4. - U-7 wt% Mo TTT Diagram. Curves for the start of the transformations.

6. ISO 9001 Certification

One implicit requirement of this LEU fabrication program was to submit all its activities to an internationally recognized Quality Management System (QMS). In the year 1999 the decision to implement a QMS based on ISO 9001 was made and a quality certification project was implemented.

The main result of this project has been the ISO 9001 certification delivered to CCHEN's Fuel Fabrication Plant in March 2003, by BVQI. The scope of this certification is the " design and fabrication of low enrichment uranium (LEU) fuels for research nuclear reactors".

7. Conclusion

The main conclusion, after five years of work in this program, is that CCHEN through its fuel fabrication plant has developed a LEU fuel fabrication capability. This capability has, on one hand, accomplished the goals set by the RERTR program, i.e. the research reactors conversion from HEU to LEU fuel, and on the other, fully satisfies the current and future LEU fuel needs of the Chilean research reactors.

8. Acknowledgements

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9. References

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